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The Use of CAD/CAM Templates in a Lateral Sinus Floor Augmentation Procedure: A Systematic Review

Maxillary sinus floor augmentation (SFA) is a procedure known for its long-term success and predictable outcomes. However, sinus membrane perforation remains the most common complication associated with this procedure. This systematic review aims to determine the presence of complications during maxillary SFA procedures using CAD/CAM surgical templates. An electronic search was carried out in MEDLINE (via PubMed), Web of Science, and Scopus. A descriptive analysis of the data was performed. Studies that performed lateral SFA were included, and the CAD/CAM surgical template design and the intraoperative complications were registered. A total of 13 studies (7 case reports, 4 case series, and 2 randomized clinical trials) and a total of 94 lateral SFA procedures (84 using CAD/CAM templates and 10 without templates) were included. Three of the 84 maxillary SFA procedures using a CAD/CAM template presented intraoperative complications. Maxillary SFA performed using CAD/CAM surgical templates could be related to low rates of complications. However, due to the heterogeneity of the included articles, more standardized studies are needed to confirm these outcomes. *Int J Periodontics Restorative Dent 2025;45:253–261. doi: 10.11607/prd.6919*

Keywords: *CAD/CAM surgical templates, complications, guided surgery, maxillary sinus floor augmentation*

Maxillary sinus floor augmentation (SFA) is a regenerative intervention performed to provide sufficient bone height and width in the posterior maxilla to place dental implants.[1] Two main approaches have been described for bone grafting the maxillary sinus[2]: The transcrestal approach and the lateral SFA approach. The transcrestal approach was first described by Tatum in 1986.[3,4] During this approach, implants are usually placed in the same surgical intervention and stabilized in the remaining native bone ridge.[4–9] The lateral SFA approach was described by Boyne and James for the first time in 1980.[10,11] It consists of creating a window in the lateral sinus wall, wide enough to introduce the instruments to elevate the sinus membrane, and the introduction of a bone substitute in the newly created compartment.[12] The most frequent surgical complication is sinus membrane perforation.[13]

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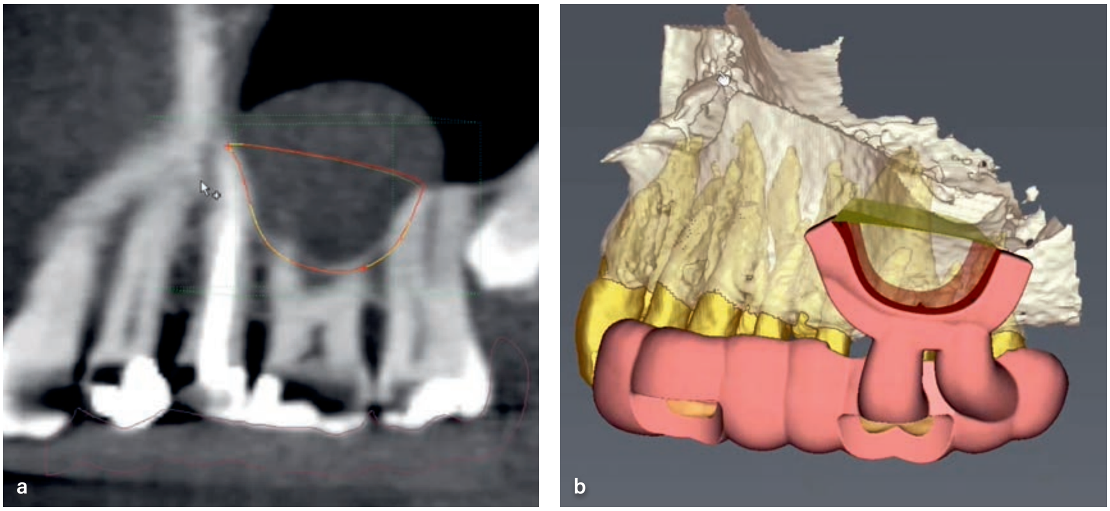

▲ **Fig 1** Example of a surgical template design. *(a)* CBCT image of the maxillary sinus area. *(b)* STL and DICOM files were combined in the CAD/CAM surgical template design.

In both techniques, the absence of complications is mainly related to correct planning and the surgeon's clinical skills. However, other variables must be considered, such as previous sinus pathology, presence of bone septum, sinus membrane thickness, adjacent roots position, and maxillary arteries trajectory and caliber. In this context, it is important to have a 3D preoperative assessment and visualization of the anatomical structures before the surgical procedure.[13,14]

Integrating DICOM data from CBCT scans into surgical software enables a virtual simulation of the surgical procedure before its actual implementation. The application of CAD/CAM technologies further contributes to accurately translating the virtual intervention to the surgical site. This is achieved through the creation of a customized surgical template for each case, ensuring a less-invasive approach and mitigating potential complications.[15,16]

To fabricate a CAD/CAM surgical template, the combination of both standard tessellation language (STL) files and DICOM files allows for their management within the surgical planning software (Fig 1). After designing the surgical template, it needs to be exported and manufactured by a 3D printer or milling unit. Subsequently, during the lateral sinus procedure after flap release, this template is precisely fitted into position and utilized to accurately outline the bone window, facilitating the performance of the lateral wall osteotomy.[17]

This systematic review aims to determine the incidence of intraoperative complications during the SFA procedure using CAD/CAM surgical templates.

Materials and Methods

This systematic review was structured according to the PRISMA statement.[18]

Focused Research Question

The study aimed to answer the following PICO (P = patient/population/problem; I = intervention; C = comparison; O = outcome) question: In patients requiring the lateral SFA procedure for implant placement (P), what is the incidence of complications (O) associated with utilizing a computer-assisted surgical procedure (I) compared to the freehand approach (C)?

- P: Patients requiring the lateral SFA procedure for implant placement
- I: Utilizing a computer-assisted surgical procedure for lateral SFA
- C: Conventional freehand performance of lateral SFA

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- O: The incidence of complications associated with the lateral SFA procedure when using a computer-assisted surgical technique

Inclusion and Exclusion Criteria

Articles published in English about performing lateral SFA in humans were considered for inclusion. The following article types were included: randomized controlled trials, nonrandomized controlled clinical trials, prospective or retrospective cohort studies, cross-sectional studies, case-control studies, case series, case reports, and articles published in English.

Studies that met the following criteria were excluded: performing transcrestal SFA, use of navigated surgery instead of static computer-guided surgery, animal studies, studies performed on corpses, experimental laboratory studies, systematic reviews and meta-analyses, duplicated articles, books or book chapters, letters to the editor, and commentaries.

Information Sources and Search Strategy

A comprehensive search of the literature published up to December 11, 2023, was conducted in the MEDLINE (via PubMed), Web of Science, and Scopus databases. The bibliographic references of the selected articles were also screened for publications that did not appear in the initial search and might be of interest.

Two independent researchers (F.J.N.D. and J.F.P.C.) performed the search. MeSH (Medical Subjects Headings) terms, keywords, and other free terms were used with Boolean operators (OR, NOT, AND) to combine searches: (maxillary sinus lift AND surgical guides) OR (maxillary sinus lift AND surgical templates) OR (maxillary sinus elevation AND surgical guides) OR (maxillary sinus elevation AND surgical templates) OR (maxillary sinus augmentation AND surgical guides). The same keywords were used for all search platforms, following the syntax rules of each database.

Study Records

Two researchers (F.J.N.D. and J.F.P.C.) independently compared results to ensure completeness and remove duplicates. Then, the full title and abstracts of the remaining papers were screened individually. Finally, full-text articles included in this systematic review were selected according to the inclusion criteria. Disagreements over which eligible studies were to be included were discussed with a third reviewer (E.K.), and a consensus was reached. Agreement between reviewers was measured with the Kappa coefficient. The results were also expressed in percentages as the concordance between reviewers. If necessary, study authors were contacted for clarification or missing information.

Risk of Bias in Individual Studies

Two authors (E.K. and J.F.P.C.) assessed the quality and risk of bias of the included studies. The Joanna Briggs Institute (JBI) Prevalence Critical Appraisal was completed for each,[19] which incorporates 10 domains. The studies were classified as low-quality assessment studies (0 to 5 domains) or high-quality assessment studies (6 to 10 domains). Any disagreement between the examiners was resolved by discussion until an agreement was reached.

Results

Study Selection

The search strategy resulted in 276 results, of which 147 remained after screening and removing duplicates. Then, two independent researchers (F.J.N.D. and J.F.P.C.) reviewed all of the titles and abstracts and excluded 126 articles outside the scope of the present review. Thus, 21 potential references were obtained. After reading the full text of those 21 articles, 8 were discarded for not meeting inclusion criteria. Therefore, 13 studies were included in this systematic review (Fig 2).

There was a 91.77% concordance between the two authors with a Kappa coefficient of 0.720 (SE: 0.09; 95%CI = 0.448, 0.797) for titles and abstracts, as well as a 95% concordance with a Kappa coefficient of 0.876 (SE 0.09; 95%CI = 0.602, 1.044) for full-text articles. Therefore, the concordance strength was “good” for titles and abstracts and “very good” for full-text articles.

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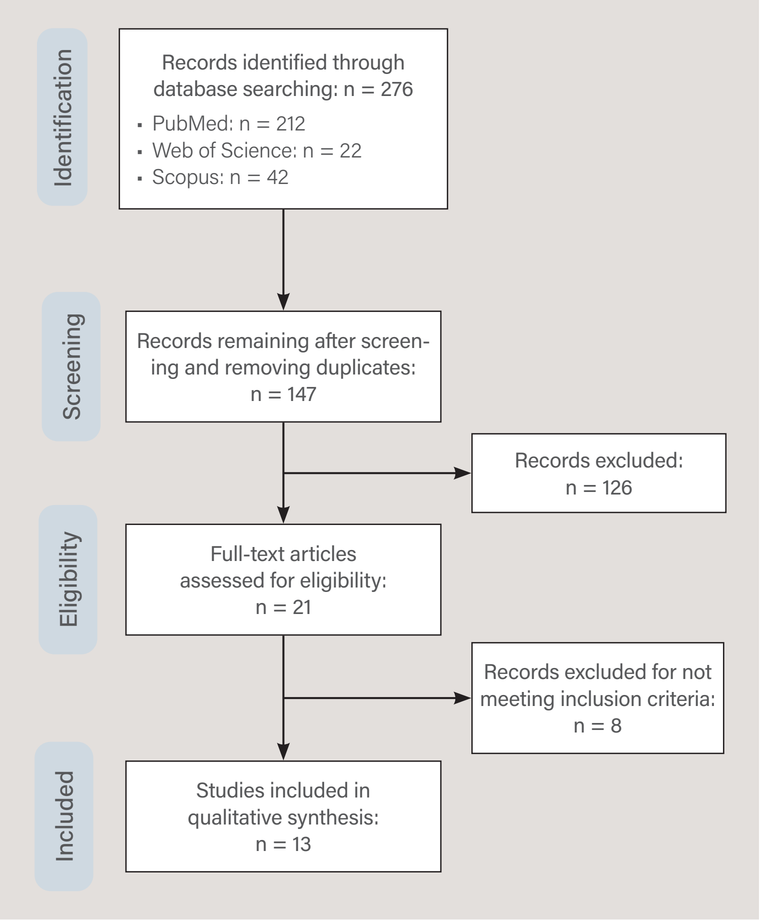

Fig 2 PRISMA flowchart of the search strategy.

Study Characteristics

A total of 13 studies were included[17,20–31]: 7 case reports, 4 case series, and 2 randomized clinical trials (RCTs). The descriptive characteristics of each study and the complications presented are available in Table 1.

A total of 94 lateral SFA procedures were included: 84 using CAD/CAM templates and 10 without using templates. Of the 84 lateral SFA using a CAD/CAM template, 3 presented intraoperative complications: One RCT by Osman et al[20] used a control group of 10 cases without surgical templates, and 3 of those cases presented complications.

Regarding the type of complications in the SFA procedures using CAD/CAM surgical templates, all of them were described as perforations of the sinus membrane during its reflection.

Seven case reports[17,21–26] performed similar procedures. They presented patients who underwent lateral SFA using CAD/CAM surgical templates. All of them were positioned on the bone surface after performing a mucoperiosteal flap. In 2008, Mandelaris et al[21] reported not using any fixation method for the template, but in their 2009 case report,[22] mini screws were used. Strbac et al[23] used pins, meanwhile Sun et al,[24] Wang et al,[25] and Teixeira et al[26] utilized a tooth-supported surgical template. Moreover, they incorporated a 3D-printed protector to keep the sinus membrane reflected during implant osteotomies. No complications were reported in these case reports.[23,24]

Osman et al[20] divided their sample of 20 patients into two groups of 10 patients, with one group utilizing surgical template during SFA and the other without templates. The group utilizing surgical templates did not present any complications, meanwhile the other group presented three membrane perforations and one hemorrhage during osteotomy, and one case required a modification to the window position during the procedure.

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Table 1 Descriptive Characteristics and Complications of Selected Studies

	Goodacre et al,[17] 2018	Osman et al,[20] 2008	Mandelaris et al,[21] 2008	Mandelaris et al,[22] 2009	Strbac et al,[23] 2020	Sun et al,[24] 2020	Wang et al,[25] 2023
Country	USA	Egypt	USA	USA	Austria	USA	China
Place of execution	Univ	Univ	PP	PP	Univ	Univ	Univ
Type of study	CR	QE	CR	CR	CR	CR	CR
Procedure	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation
Guide support	Tooth-supported	Titanium screws	Bone-supported	Titanium screws	Pins	Tooth-supported	Tooth-supported
Patients, n	1	15	1	1	1	1	1
Gender	NS	M 9 F 6	M 1	F 1	F 1	F 1	NS
Intervened sinuses, n	1	20	1	2	1	1	1
Complications, n (type)	0	1 GS 3 SS (membrane perforation)	0	0	0	0	0
Residual bone height	NS	4–6 mm	NS	NS	4–9 mm	5–7 mm	NS
Bone height gained	NS	NS	NS	NS	NS	NS	NS
Osteotomy instrument	Round tungsten carbide bur	Round diamond bur	Round burs and piezoelectric	Round burs, piezosurgery	Piezoelectric diamond-coated ball	Piezo-electric	Round diamond bur
Implants, n	1	NS	2	2	2	2	1

	Teixeira et al,[26] 2021	Meneghetti et al,[27] 2023	Cho et al,[28] 2020	Mangano et al,[29] 2013	Zaniol et al,[30] 2018	Fouad et al,[31] 2018
Country	Brazil	USA	Korea	Italy	Italy	Egypt
Place of execution	Univ	Univ	Univ	Univ	PP	Univ
Type of study	CR	CS	CS	CS	CS	CT
Procedure	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation	Lateral elevation
Guide support	Tooth-supported	Tooth-supported	Titanium screws	None	None	Titanium screws
Patients, n	1	3	5	5	22	17
Gender	NS	M 2 F 1	M 3 F 2	M 3 F 2	M 12 F 10	M 9 F 8
Intervened sinuses, n	1	3	5	10	28	20
Complications, n (type)	0	0	0	0	0	2 GS (membrane perforation)
Residual bone height	< 1.5 mm	4–5.34 mm	< 4 mm	2–5 mm	2–4 mm	4–6 mm
Bone height gained	NS	NS	NS	NS	NS	4.05–9.7 mm
Osteotomy instrument	Piezoelectric	Diamond bur, piezoelectric	High-speed bur	Piezosurgery inserts	Piezoelectric	Diamond bur
Implants, n	NS	3	12	19	79	34

CR = case report; CS = case series; CT = clinical trial; F = female; GS = guided surgery; M = male; NS = not specified; PP = private practice; QE = quasi-experimental study; SS = standard unguided surgery; Univ = university.

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Table 2 Case Series Risk of Bias

	Meneghetti et al,[27] 2023	Cho et al,[28] 2020	Mangano et al,[29] 2013	Zaniol et al,[30] 2018
Were there clear criteria for inclusion in the case series?	+	+	+	+
Was the condition measured in a standard, reliable way for all participants included in the case series?	+	+	+	+
Were valid methods used for identification of the condition for all participants included in the case series?	+	+	+	+
Did the case series have consecutive inclusion of participants?	+	–	+	+
Did the case series have complete inclusion of participants?	?	–	+	–
Was there clear reporting of the demographics of the participants in the study?	+	+	+	+
Was there clear reporting of clinical information of the participants?	–	–	–	–
Were the outcomes or follow-up results of cases clearly reported?	+	+	+	+
Was there clear reporting of the presenting site(s)/clinic(s) demographic information?	+	+	+	+
Was statistical analysis appropriate?	?	–	–	+

+ = low risk of bias; ? = unclear risk of bias; – = high risk of bias.

Meneghetti et al[27] placed three immediate implants after SFA in three patients, using surgical templates as a part of the implant surgical guide. An ideal 3D position was obtained during SFA and simultaneous implant placement. They did not report any associated complications.

Cho et al[28] and Mangano et al[29] both presented a case series. Each reported on five patients who had a lateral SFA using CAD/CAM surgical templates, and both reported a high level of adaptation of the guides to the maxilla without any complications during the surgical procedures.

Mangano et al[29] kept the template in position during the lateral wall osteotomy; meanwhile, Cho et al[28] utilized the template only to mark the window outline, then removed the guide before performing the osteotomy. This was also done by Zaniol et al.[30] Neither study reported membrane perforations nor intraoperative complications.

Fouad et al[31] compared the effectiveness of implant placement in lateral SFA procedures with or without bone grafting. They performed 20 surgeries, divided into two similar groups, always using CAD/CAM stents. The authors removed the surgical templates after completing the bone wall window. Two complications were reported, both membrane perforations during membrane reflection.

Risk of Bias

Three authors (F.N., E.K., and J.F.P.C.) independently performed the risk of bias and study quality analyses. The predetermined 10 domains for the methodologic quality assessment (according to JBI Prevalence Critical Appraisal Tool) were used. Data are presented in Tables 2 and 3.

Discussion

While the SFA technique is generally predictable, sinus membrane perforation remains the most common complication associated with this procedure.[32] Some authors assert that membrane perforation occurs more frequently during the lateral window osteotomy rather than during membrane reflection.[33] The inadequacy of osteotomy design may contribute to membrane perforations, and characteristics such as mucosal thickness may impact the risk of perforation.[33,34]

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Table 3 Randomized Controlled Trials Risk of Bias

	Osman et al,[20] 2018	Fouad et al,[31] 2018
Was true randomization used for assignment of participants to treatment groups?	?	+
Was allocation to treatment groups concealed?	–	–
Were treatment groups similar at baseline?	+	+
Were participants blind to treatment assignment?	?	?
Were those delivering treatment blind to treatment assignment?	–	–
Were outcome assessors blind to treatment assignment?	?	?
Were treatment groups treated identically other than the intervention of interest?	+	+
Was follow-up complete, and if not, were differences between groups in terms of their follow-up adequately described and analyzed?	+	+
Were participants analyzed in the groups to which they were randomized?	+	+
Were outcomes measured in the same way for treatment groups?	+	+
Were outcomes measured in a reliable way?	+	+
Was appropriate statistical analysis used?	+	+
Was the trial design appropriate and any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	+	+

+ = low risk of bias; ? = unclear risk of bias; – = high risk of bias.

Additionally, approximately one-third of patients present with a sinus septum, varying in shape and size, which further complicates membrane elevation and elevates the risk of perforation.[33] Accidental injuries to arteries surrounding the sinus—such as the infraorbital, palatine, and posterior superior alveolar arteries—can lead to bleeding. Utilizing digital advancements, such as treatment planning, can enhance surgical precision through the use of surgical CAD/CAM templates.

In this review, three intraoperative complications were identified within a total of 93 lateral SFA procedures utilizing CAD/CAM templates. This demonstrates a lower incidence of complications compared to procedures conducted without templates, as reported in other studies, where membrane perforations ranged from 15.7% to 44%.[32,35,36] As evidenced, sinus membrane perforation remains the most common complication associated with this procedure, both with and without the use of surgical stents.

According to the included studies, the CAD/CAM surgical template proves effective in delineating the surgical window in the maxilla's cortical lateral wall to access the sinus. The template may be either retained or removed during subsequent steps of the procedure,[31,37] although in most cases, removal is necessary to facilitate easier access of reflection instruments into the bone window.

Despite the potential for extended durations in surgical planning and template fabrication compared to free-hand surgery (due to the comprehensive planning process), the benefits may outweigh the time investment. The reduction in complications observed with a digital planning approach justifies its adoption.[22] Virtual surgical planning is particularly recommended in cases with anatomical anomalies, such as proximity of tooth roots to the sinus wall, tooth roots within the sinus, septum presence, thin cortical bone, or cases with a higher risk of sinus membrane damage.

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Comprehensive 3D virtual surgical planning provides clinicians with relevant clinical information before the surgical procedure, improving preparation for critical steps, particularly the lateral window osteotomy during SFA.[38]

The diverse range of surgical templates employed by different authors reflects the varied approaches and advancements in digital dentistry. While utilizing a similar protocol involving DICOM and STL files within implant-planning software, significant variations in guide design methodologies exist, impacting guide stability and accuracy, as well as the incidence of complications. For instance, Meneghetti et al[27] introduced a guide that facilitates simultaneous lateral SFA and implant placement. In contrast, Mandelaris et al[21] and Osman et al[20] integrated the surgical guide with the template as a unified single unit. On the other hand, Strbac et al[23] adopted a template that mirrored precise virtual implant positions but utilized two separate surgical templates derived from the same file, thereby segregating the implant position from the lateral window. Sun et al[24] introduced a template featuring a platform extension into the sinus cavity, providing support during membrane elevation and implant osteotomy.

The identification of discrepancies between planned and actual outcomes underscores the limitations associated with single-piece guides, primarily attributed to anatomical morphology.[27] Consequently, the potential benefits of utilizing two-piece guides are evident, suggesting that such an approach could enhance adaptation and accuracy in surgical procedures.[27]

A primary limitation of this review pertains to the quality of articles meeting the inclusion criteria for analysis, as most are case reports or case series with a low level of evidence. Additionally, heterogeneity among articles arises from differences in digital surgical template designs, retention systems, and instrumentation during membrane reflection. Consequently, external validation through prospective standardized studies is imperative to confirm these outcomes.

Conclusions

SFA performed using CAD/CAM surgical templates may be associated with low complication rates, but further standardized studies are essential to confirm these findings due to the heterogeneity observed in the included articles.

Acknowledgments

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